Multidisciplinary High-Fidelity Analysis of Aerospace Vehicles: **Overview of HSCT4.0 Application**

Jim Townsend

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ASCAC Methods Development Peer Review

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HSCT4.0 — Outline

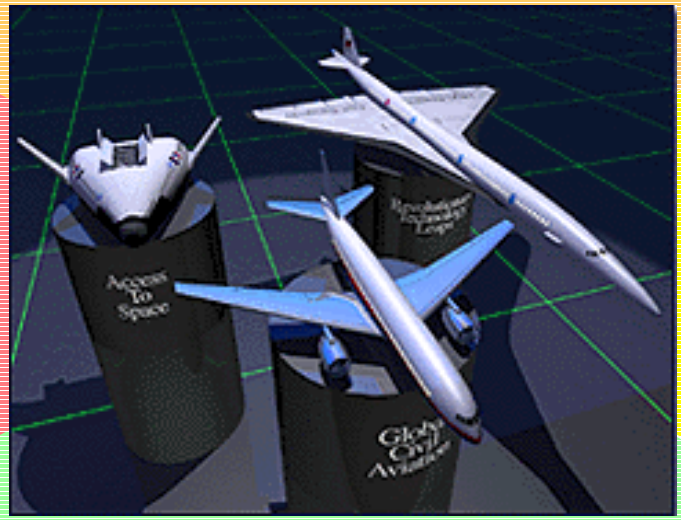
- Background:
  - **Purpose of HSCT4.0**
  - **History**
- Technical Aspects:
  - **Configuration (Aero + FEM models)**
  - **Analysis process**
  - **Framework – Environment (CJOpt)**
  - **Sample results**
- Outcome:
  - **Accomplishments**
  - **Lessons Learned**

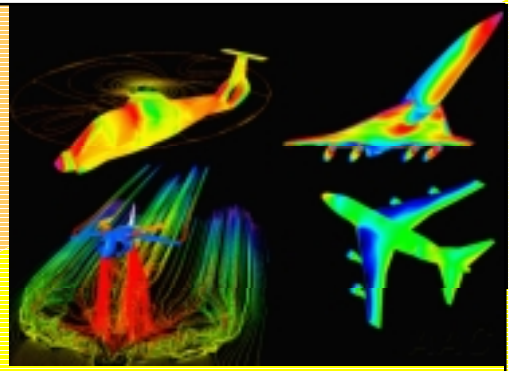
HSCT4.0 Support

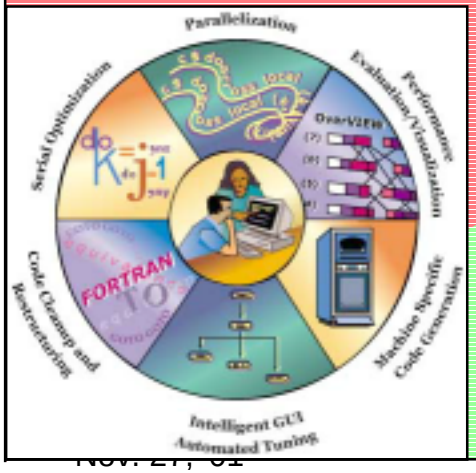
- Federal High Performance Computing and Communication Program (HPCCP)
  - Computational Aerospace Sciences Team
    - Project leadership
  - NASA LaRC civil servants (~5 FTEs)
    - **Bob Weston, Joanne Walsh, Jim Townsend, Andrea Salas, Jamshid Samareh, Vivek Mukhopadhyay, Brian Mason, Larry Green, Bob Biedron, Jean-Francois Barthelemy, and others**
    - Problem formulation
    - Discipline analyses
    - Documentation
  - CSC contractor team (~4 FTEs)
    - **Phil Su, Raj Sistla, Ram Shan, Tham Murthy, Gus Dovi, and others**
    - Software integration
    - Documentation

HPCC Program (1992-2001)
(High Performance Computing and Communications)

- **Computational AeroSciences Goal**
  - Enable improvements to NASA technologies and capabilities in aerospace transportation through the development and application of high-performance computing technologies and the infusion of these technologies into the NASA and national aerospace community





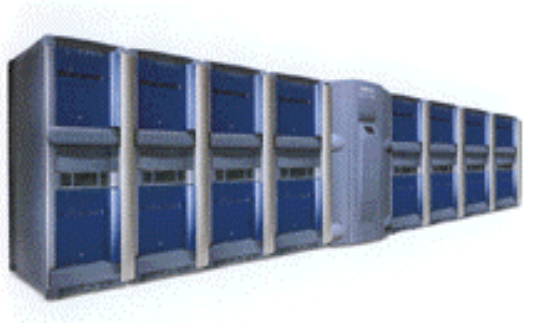


HSCT4.0 Motivation

- **Meet the LaRC HPCCP-CAS goal**
  - Demonstrate the use of **high performance computing** for a **challenging MDO application**
    - Use **high-fidelity** finite-element **structural** and computational fluid **aerodynamic** analyses
    - Use **distributed**, **heterogeneous** computing environment
    - Use high performance **parallel** computing
- **Support High Speed Research (HSR) program**
  - Be **realistic enough** to interest the aerospace industry
  - Aid in configuration decisions in 2000

HSCT4.0 History

1992 NASA LaRC decisions:



- Began research into automating Multidisciplinary Design Optimization (MDO) with high-fidelity analysis codes
  - Exploit HPCC as Grand Challenge application focus
- Selected High Speed Civil Transport (HSCT) as focus application
  - Exploit synergy with the High Speed Research (HSR) program

By 1999:

- Evolved into the HSCT4.0 application
  - Research endeavor in both MDO and HPCC
  - Unique combination of disciplinary breadth and depth in MDO research

In 2000: HSR cancelled ➠HSCT4.0 cancelled

HSCT4.0 Built on Past Successes

- 1992 Demonstration of hard-coded framework **(FIDO)**
- 1994 Communications Library added
  - Weston, R. P., Townsend, J. C., Eidson, T. M., and Gates, R. L., **"A Distributed Computing Environment for Multidisciplinary Design,"** ***Proceedings of the 5th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*****, Part 2,** Panama City, FL, 1994, pp. 1091–1097
- 1996 Medium-fidelity codes added
  - Krishnan, R., Sistla, R., and Dovi, A. R., **"High-Speed Civil Transport Design Using FIDO,"** NASA CR-1999-209693, Oct. '99
- 1998 Object-oriented environment (CJOpt)
  - Sistla, R., Dovi, A. R., and Su, P., **"A Distributed, Heterogeneous Computing Environment for Multidisciplinary Design & Analysis of Aerospace Vehicles,"** ***5th National Symposium on LARGE-Scale Analysis, Design and Intelligent Synthesis Environments*****,** Oct 12–15, 1999, Williamsburg, VA
- 1998 Software configuration management
  - Townsend, J. C., Salas, A. O., and Schuler, M. P., **"Configuration Management of an Optimization Application in a Research Environment,"** NASA / TM-1999-209335, June 1999
- Past HSCT analyses (e.g., **Pathfinder, LCAP**)

History of HPCCP – HSCT Applications

Application: (years)	**HSCT2.1** (‘94 – ‘96)	**HSCT3.5** (‘95 – ‘97)	**HSCT4.0** (‘97 – ‘99)
Emphasis:	**Framework evolution**		**Application**
Design Variables	**5**	**7**	**271**
Constraints	**6**	**6**	**O(10,000)**
Major Legacy Code Complexity	Low	Low–medium	Medium–high
Analysis Processes (without looping)	**10**	**20**	**70**
Analysis Control			
Major Loops	Weight Conv., Trim	Weight Conv., Aeroelastic, Trim	Weight Conv., Aeroelastic, Trim
Load conditions	**2**	**2**	**8**
Mission conditions	1	1	10
Processes (with loops)	O(10)	O(100)	O(1000)
Total time	**O(minutes)**	**O(hours)**	**O(1 day)**

Industry Input

- **Aerodynamic model – Boeing**
- **Finite element model (FEM) – Boeing**
- **Advice on load cases – MacDonnell-Douglas**
- **Advice on acceptable codes, etc.**
- **Discussions on process**

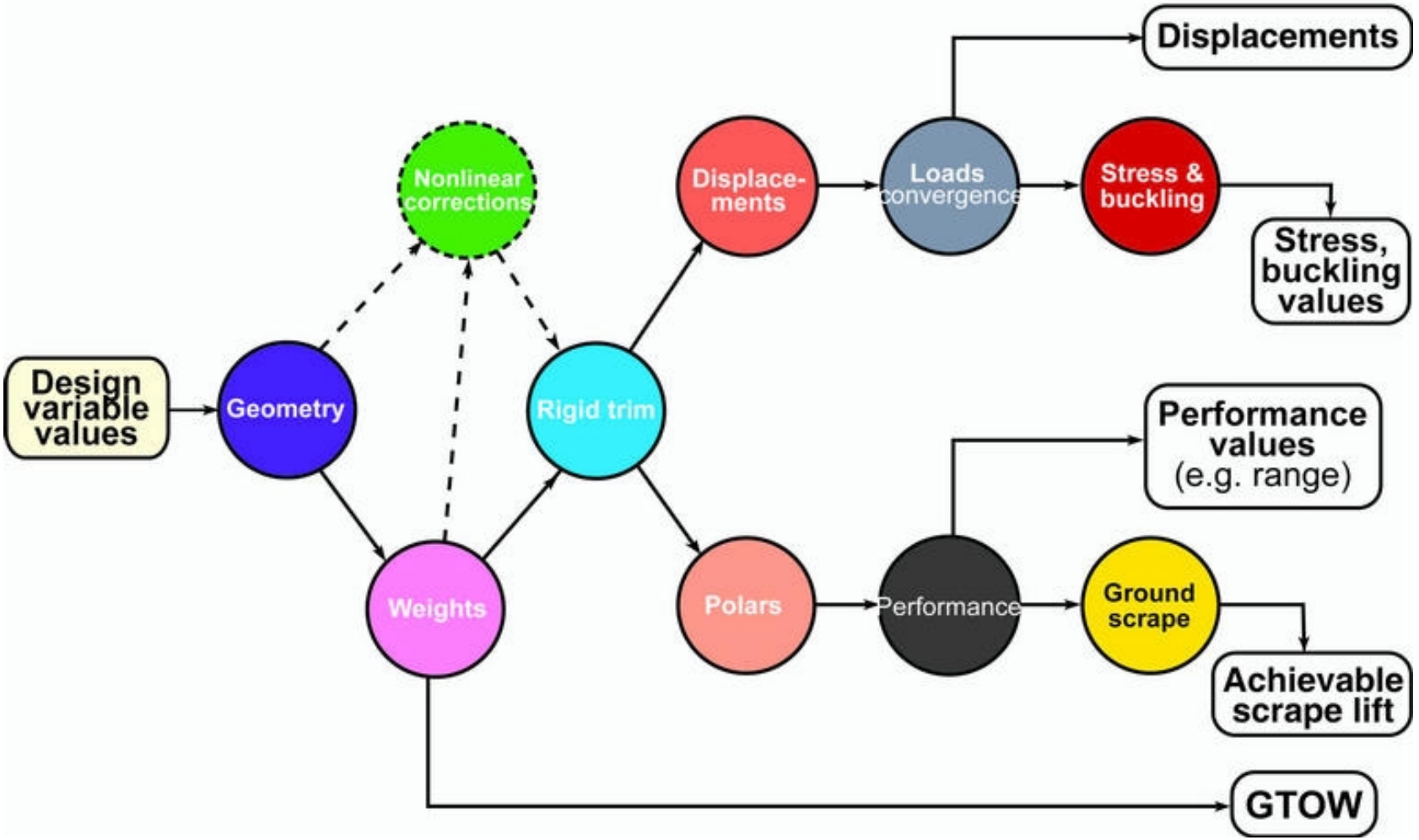
LCAP Legacy

- **Same finite element model**
- **Reuse some analysis processes**
- **Reuse some computer codes**
- **Apply lesson on need for automation**

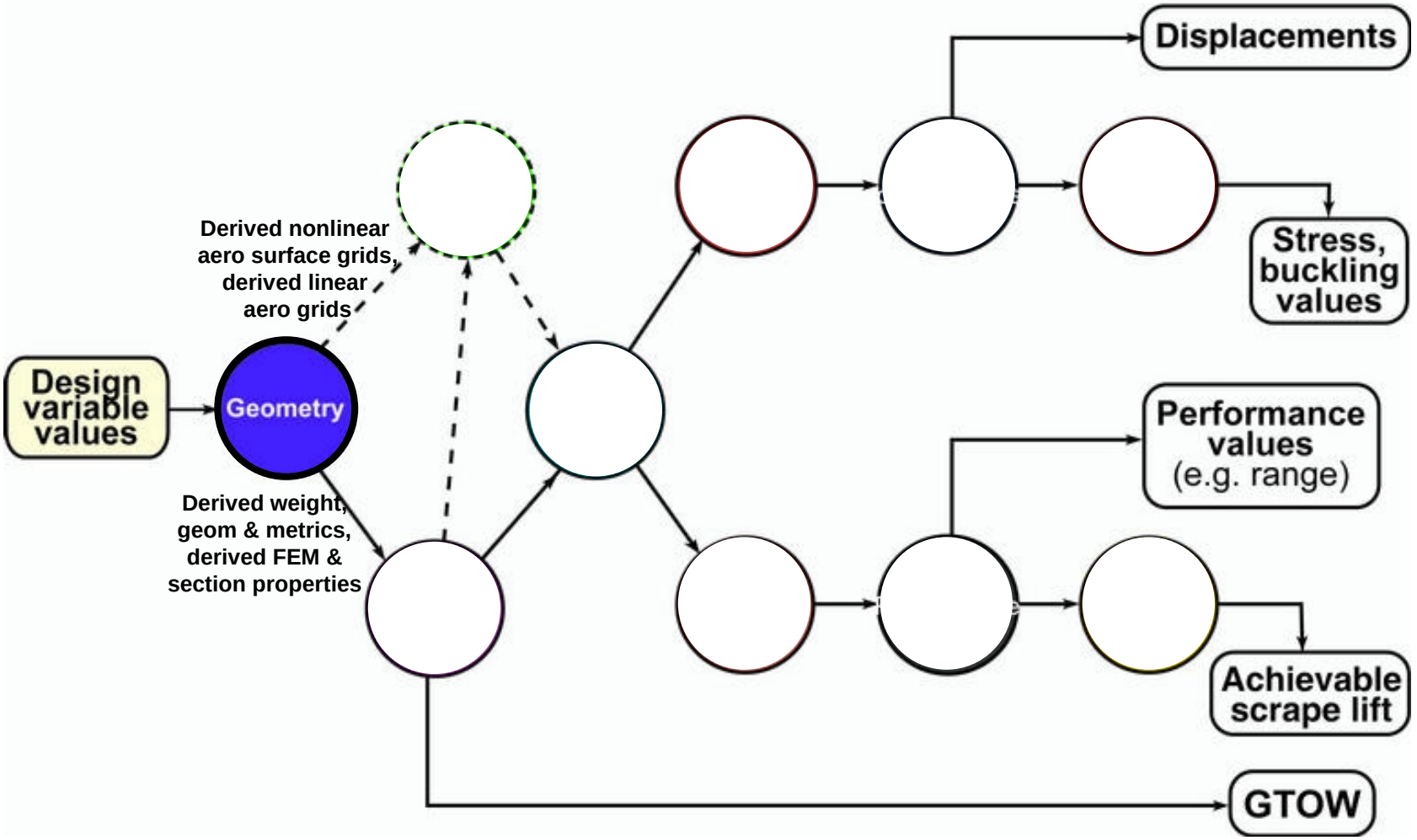
HSCT4.0 Application

- Realistic aircraft concept from Boeing
- Aerodynamic analyses of standard and medium fidelity
  - Linear (USSAERO using 1100-point surface grid)
  - Nonlinear (inviscid CFL3D using 600,000-point volume grid)
- Structural analysis of medium to high fidelity
  - GENESIS using FEM with 40,000 degrees of freedom
- Performance analysis
  - FLOPS
- Weights analysis
  - Similar to industry
- 8 load conditions
  - 1 cruise
  - 6 maneuver (2.5g & -1.0g)
  - 1 taxi

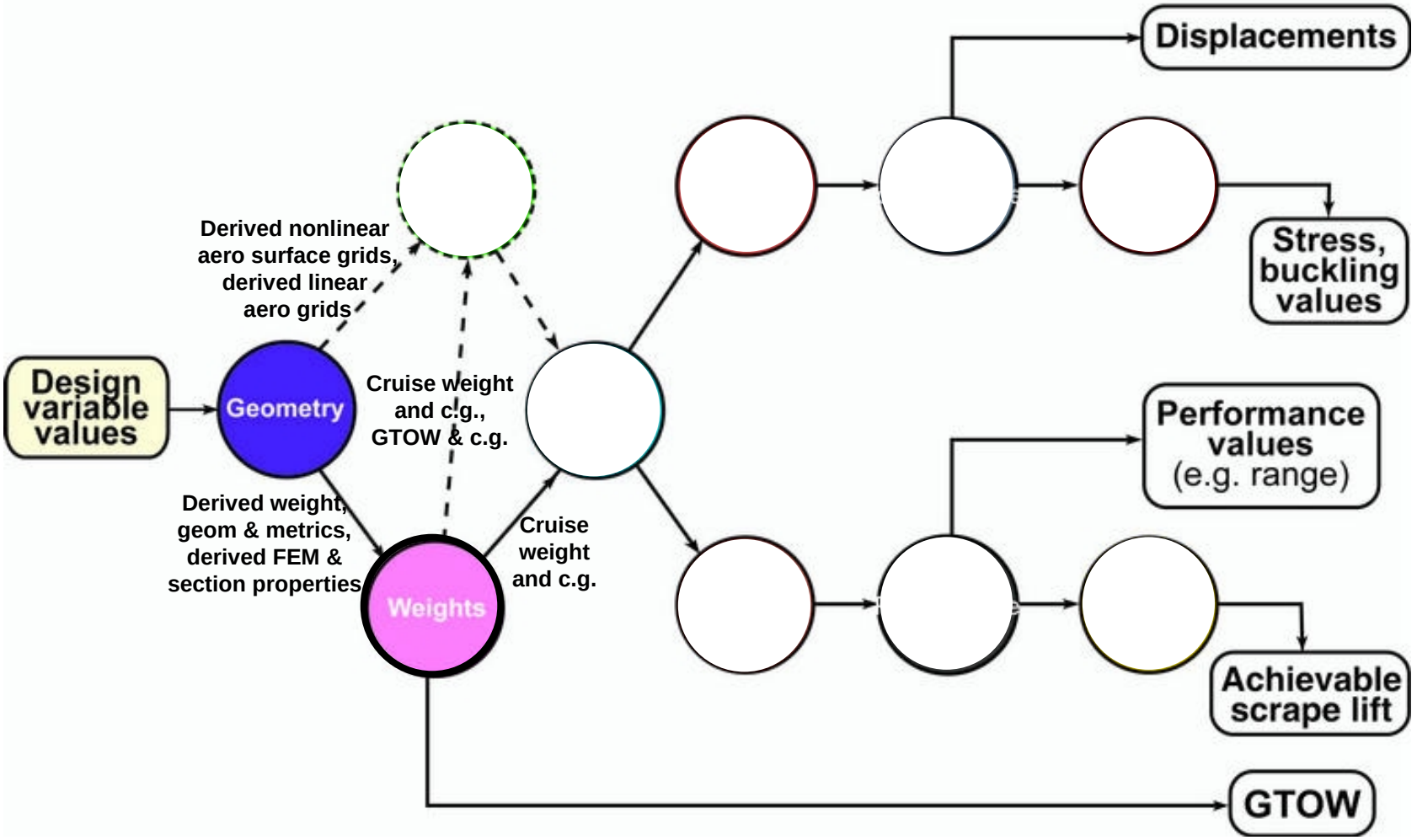
HSCT4.0 Analysis Process



HSCT4.0 Analysis Process



HSCT4.0 Analysis Process



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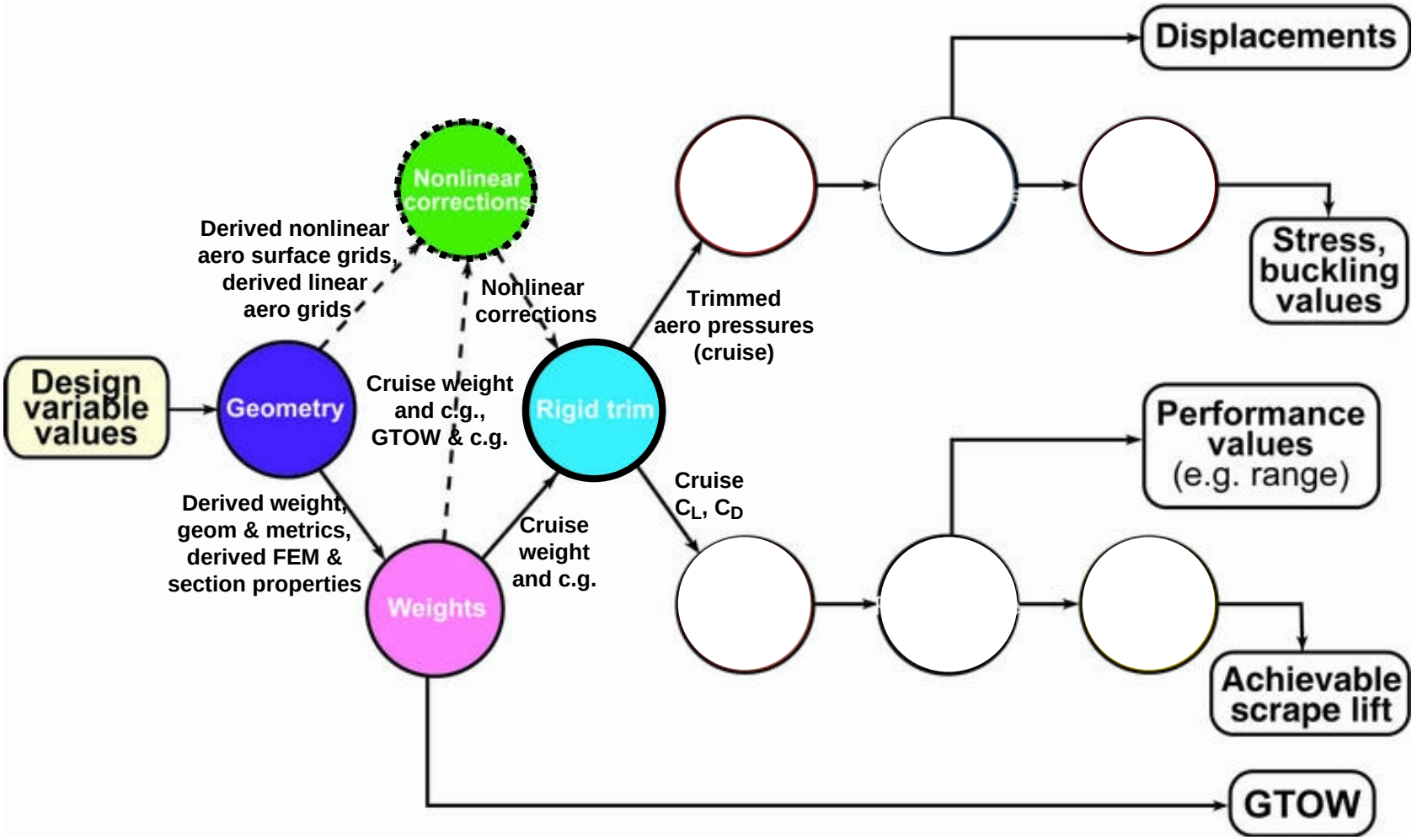
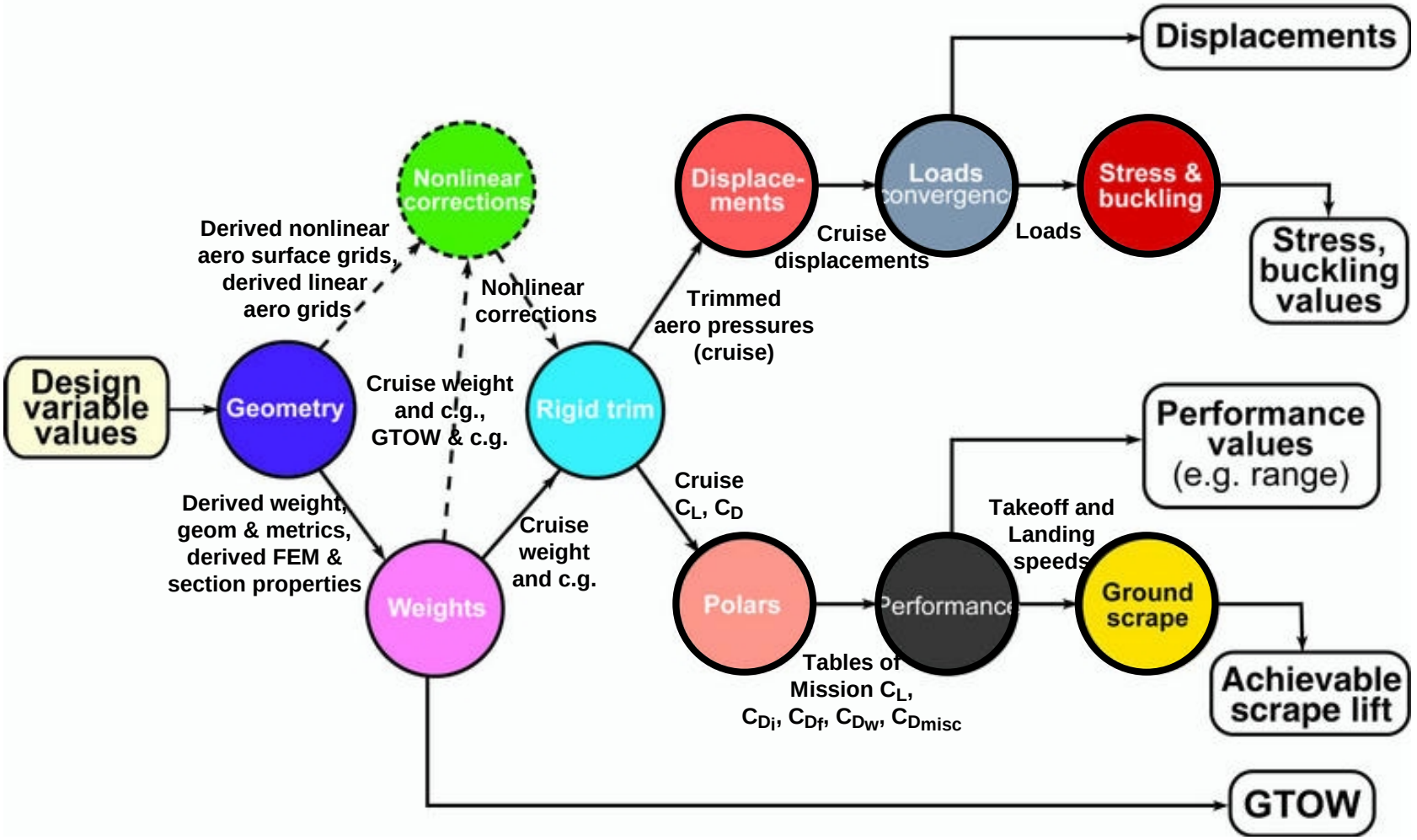
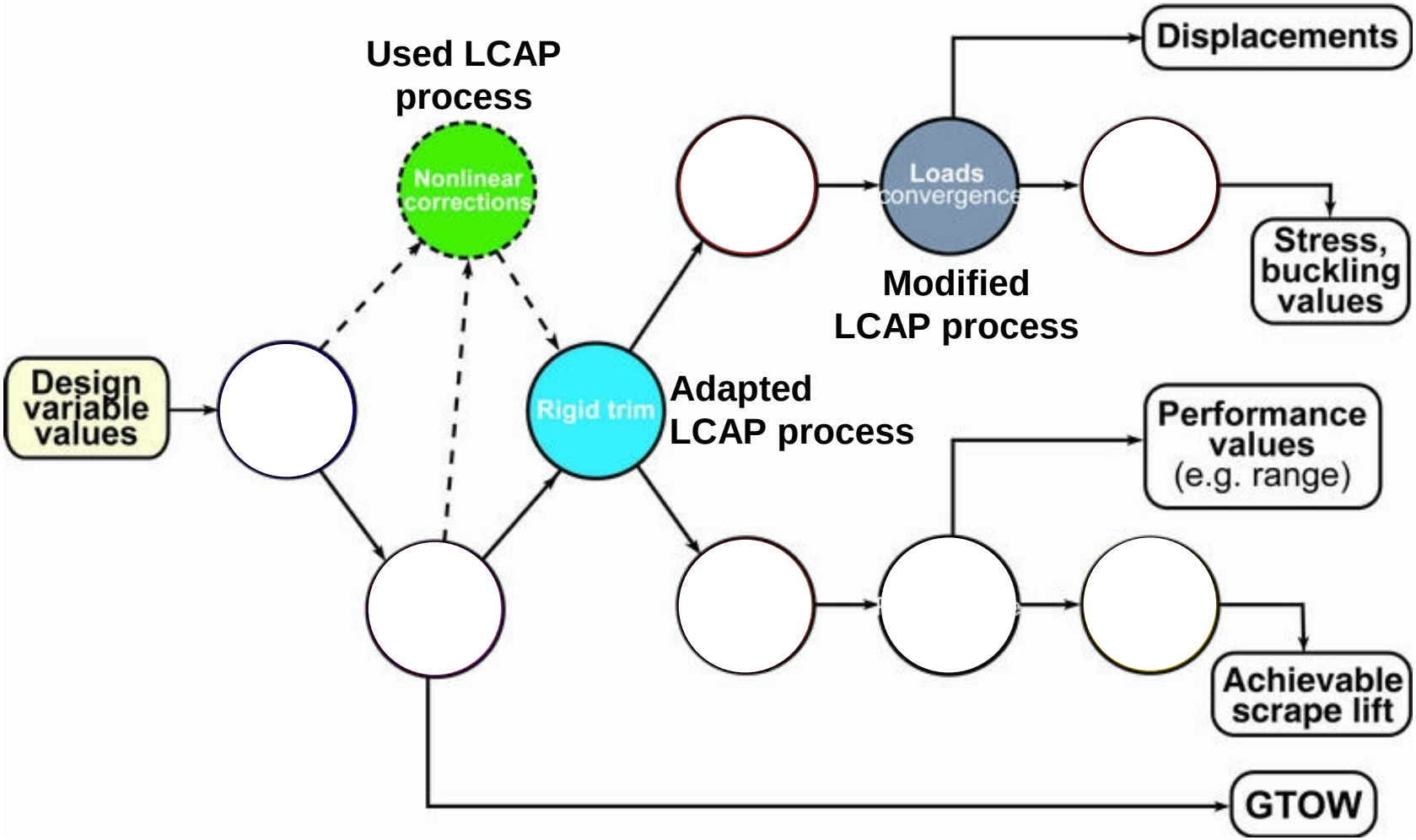


HSCT4.0 Analysis Process



HSCT4.0 Processes from LCAP



Framework – Environment

- FIDO: too rigid, too high maintenance
- No satisfactory commercial framework (1997)
- CORBA-Java Optimization (CJOpt) environment developed, based on:
  - Common Object Request Broker Architecture (CORBA)
    - Software industry standard
  - Java computer language and Application Programming Interfaces (APIs)
    - Supports object-oriented programming
  - SQL compliant database (miniSQL)
    - Common data, file name repository

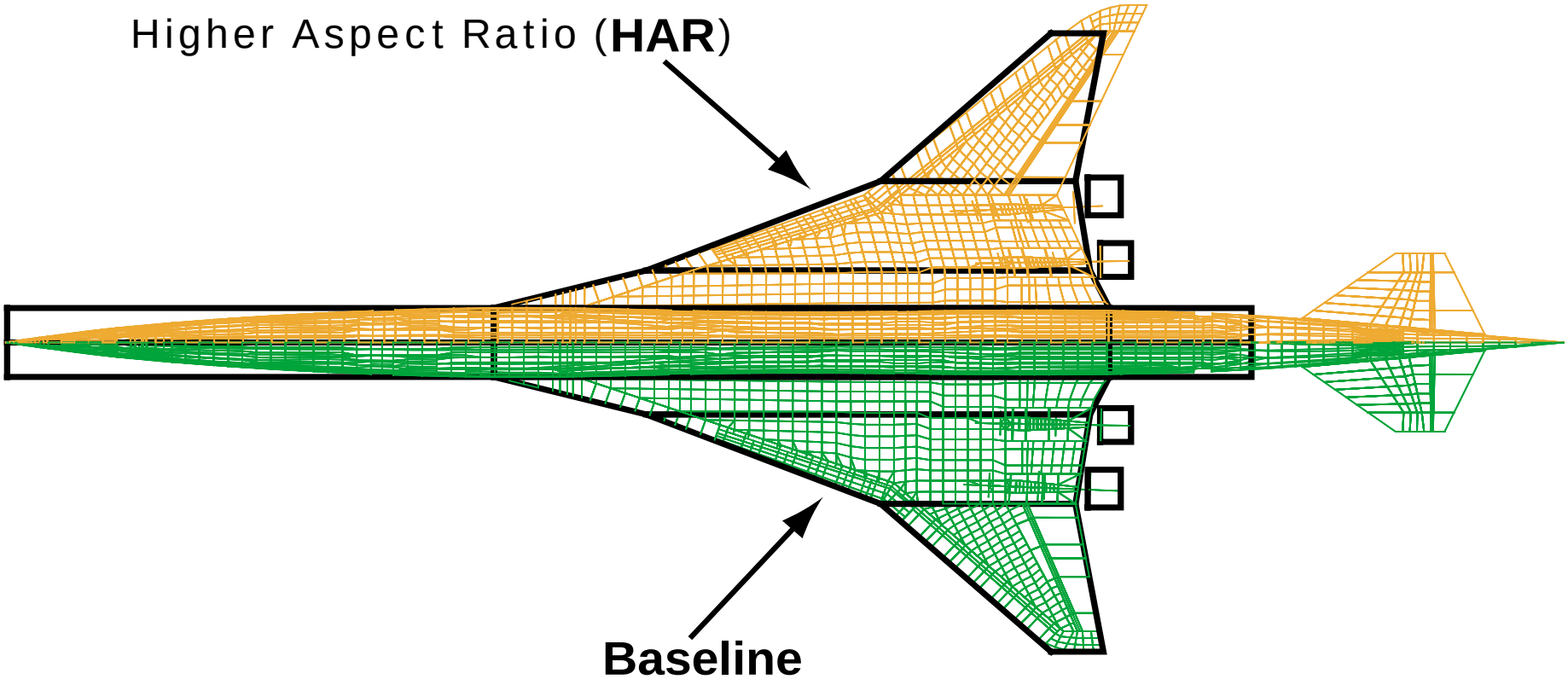
Verification

- Test cases (sets of initial design variable values)
  - Baseline
  - Higher Aspect Ratio (HAR)
- Verify integrated CJOpt results process-by-process for both test cases against "standalone codes"
  - Output files from integrated codes identical to output files obtained from running same codes in standalone mode
- Confirm that results are reasonable from an engineering standpoint
- Amount of data generated
  - 300 files
  - 200 MB total
  - 5 hrs clock time per full analysis w/o non-linear corrections

Sample Results

- **Geometry process**
- **Loads Convergence process**
- **Stress & Buckling process**

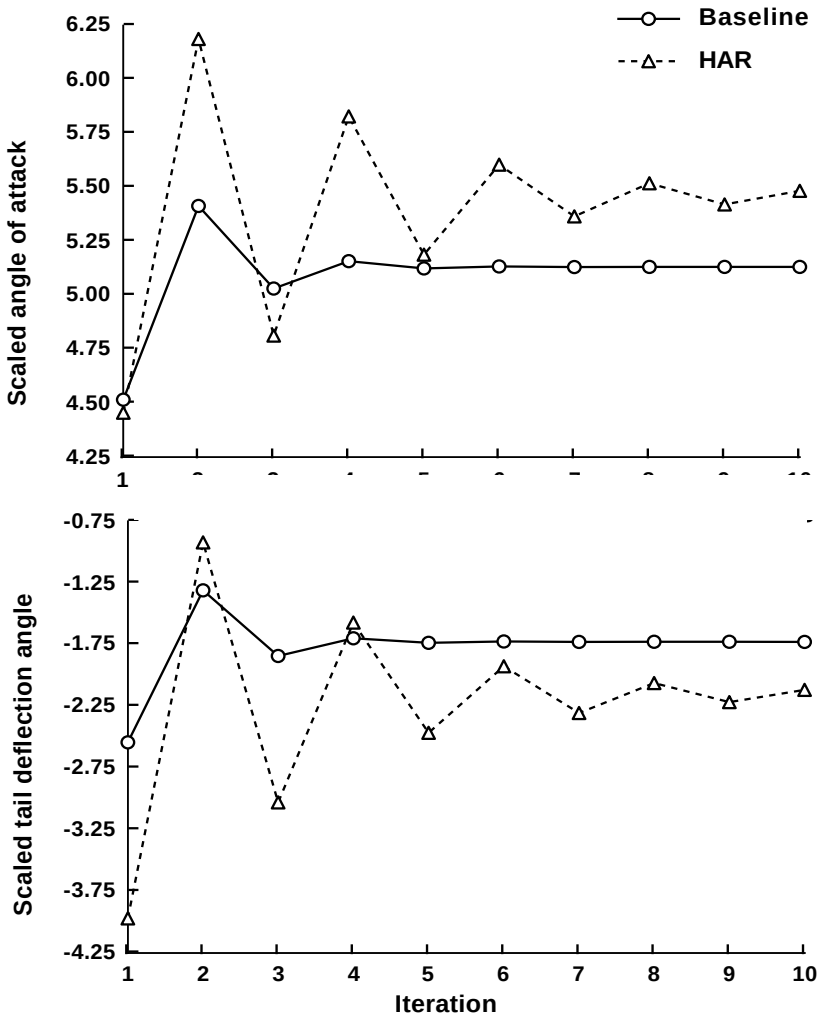
Geometry Process Results



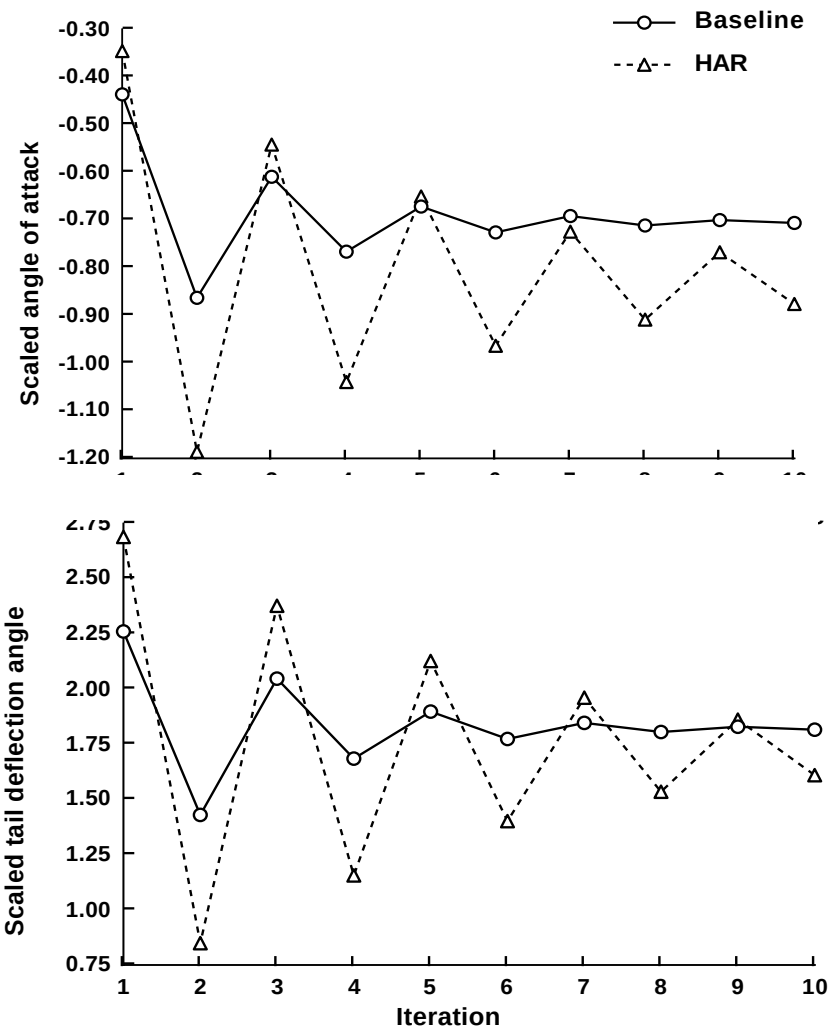
Black outlines are Baseline parameterized planform shape elements.

Loads Convergence Process Results

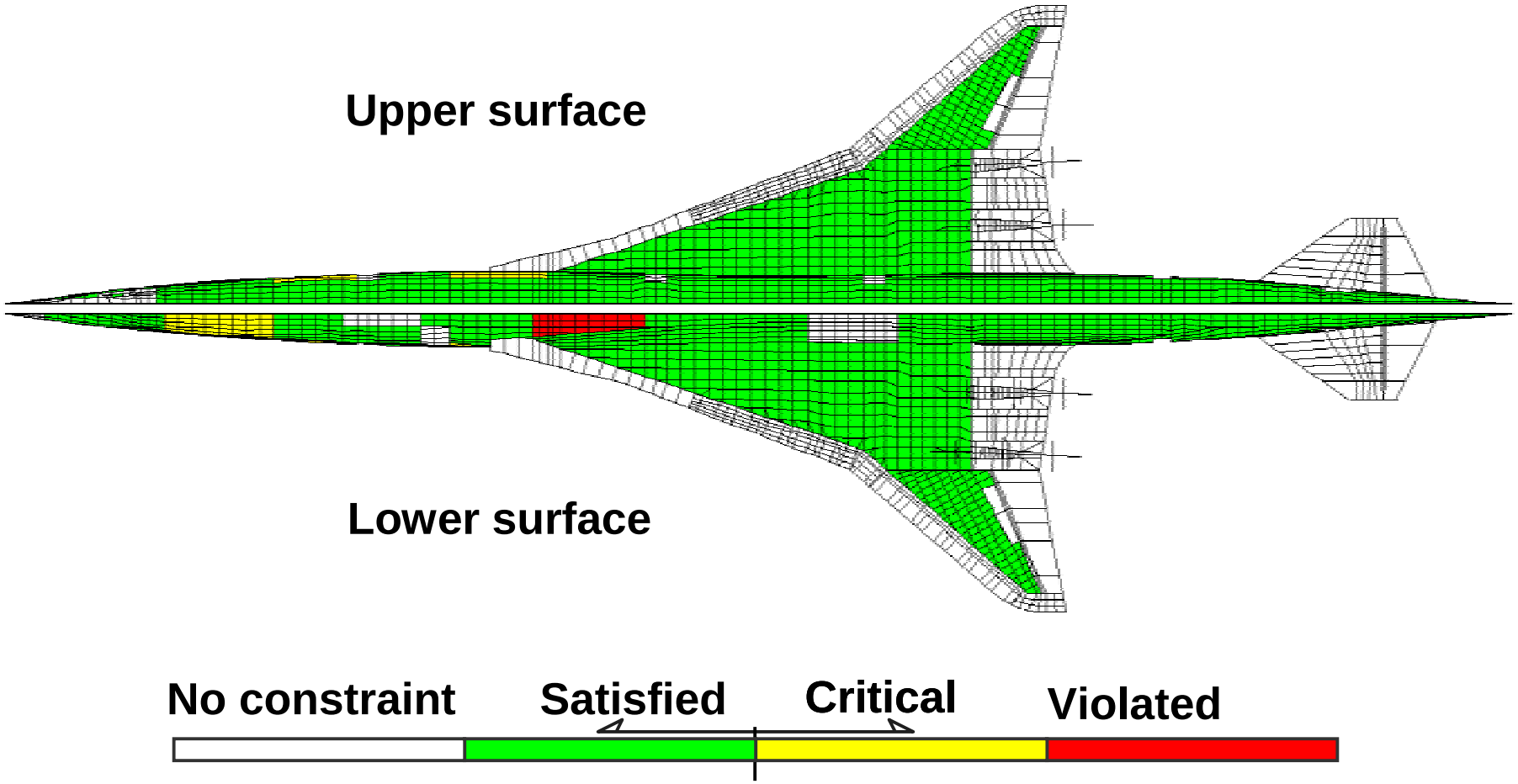
2.5g load condition



-1g load condition



Buckling Failure Criteria Results
Baseline Configuration 2.5g Load Condition



HSCT 4.0 Outcome

- **Analysis process**
  - Formulated
  - Implemented in Common Object Request Broker Architecture (CORBA) – Java environment (CJOpt)
  - Verified for 2 sets of design variable values
- **Sensitivity analysis**
  - More complex problem than expected
    - Can't apply auto differentiation to COTS code
  - Deferred by HSCT4.0 cancellation
- **Optimization**
  - Process demonstrated w/ nonlinear aero optimization
  - Full implementation deferred by HSCT4.0 cancellation
- **Lessons learned**
  - Useful to others managing complex research projects
    - E.g., ELVIS, RACRSS

Conclusions

- **Met the LaRC HPCCP-CAS goal:**
  - Demonstrated the use of **high performance computing** for a **challenging MDO application**
    - Used **high-fidelity** finite-element **structural** and computational fluid **aerodynamic** analyses
    - Used **distributed**, **heterogeneous** computing environment
    - Showed use of high performance **parallel** computing
    - Demonstrated optimization with high-fidelity CFD
- **Support for HSR program**
  - Large **increase in realism** over previous LaRC aircraft optimization efforts

Multidisciplinary High-Fidelity Analysis of Aerospace Vehicles: **Overview of HSCT4.0 Application, References**

Related Presentations:

- Jamshid A. Samareh and Kumar G. Bhatia (Boeing): A Unified Approach to Modeling Multidisciplinary Interactions, 8th AIAA/NASA/USAF/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Long Beach, CA, September 6-8, 2000.
- Joanne L. Walsh, James C. Townsend, Andrea O. Salas, Jamshid, A. Samareh, Vivek Mukhopadhyay, and Jean-Francois M. Barthelemy: Multidisciplinary High-Fidelity Analysis and Optimization of Aerospace Vehicles, Part 1: Formulation, 38th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 10-13, 2000.
- Joanne L. Walsh, Robert P. Weston, Jamshid, A. Samareh, Brian H. Mason, Lawrence L. Green, and Robert T. Biedron: Multidisciplinary High-Fidelity Analysis and optimization of Aerospace Vehicles, Part 2: Preliminary Results, 38th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 10-13, 2000.

Related Publications:

- Joanne L. Walsh, James C. Townsend, Andrea O. Salas, Jamshid, A. Samareh, Vivek Mukhopadhyay, and Jean-Francois M. Barthelemy: "Multidisciplinary High-Fidelity Analysis and Optimization of Aerospace Vehicles, Part 1: Formulation", 38th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 10-13, 2000. LTRS.
- Joanne L. Walsh, Robert P. Weston, Jamshid, A. Samareh, Brian H. Mason, Lawrence L. Green, and Robert T. Biedron "Multidisciplinary High-Fidelity Analysis and Optimization of Aerospace Vehicles, Part 2: Preliminary Results", 38th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 10-13, 2000. LTRS.
- Salas, A. O., Walsh, J. L., Mason, B. H., Weston, R. P., Townsend, J. C., Samareh, J. A., and Green, L. L., "HSCT4.0 Application Software Requirements Specification," NASA/TM-2001-210867, May 2001. LTRS.

(LTRS indicates paper available on the the NASA Langley Technical Report Server, ***http://techreports.larc.nasa.gov/ltrs/ltrs.html***.)